PROBLEMS IN CONDUCTING RESEARCH ON COMPUTER-BASED SIMULATION

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INTRODUCTION

Computer-based simulation (CBS) represents a unique utilization of computers for instruction that combines some of the best features of the technologies of simulation and computer-assisted instruction (CAI). Until a few years ago, CAI had been applied primarily to training skills such as math and foreign languages with fairly consistent demonstrations of time savings and instructional effectiveness as compared to conventional methodologies (e.g., Ford, Slough & Hurlock, 1972). CBS grew out of an interest in testing the application of CAI to procedural and perceptual motor skills; skills that traditionally had been trained with hands-on practice on real-world objects or high fidelity simulators. CBS offered the potential for low-cost simulation combined with pedagogical effectiveness.

CBS can be conceptualized as two-dimensional simulation. Computer graphics or slides are used to create representations of the appearances and dynamic operations of physical objects or environments. Typically, the simulation is programmed in the context of instructional text and feedback on a CAI system that has a cathode ray tube (CRT) or plasma panel on which the lesson materials can be displayed. An interactive situation is created in that the student can manipulate the simulation through the keyboard, touch panel, or light pen of the system. The computer evaluates this student input, presents feedback, and causes the simulated object to react much in the same way as would its real-world counterpart.

Several experimental efforts have been carried out to evaluate the efficacy of CBS for training. While the methodology is still in its infancy, the data are conducive to some preliminary generalizations concerning training considerations and CBS system features. The present paper will discuss these early findings and identify directions for future research.

TRAINING CONSIDERATIONS

CBS has been used effectively to teach several different types of tasks to a variety of students, and a number of instructional innovations have been developed as by-products; details will be presented in the following paragraphs.

Flight officers on anti-submarine aircraft have been trained to perform tactical operations tasks (Crawford, Hurlock, Padilla, & Sassano, 1976; Crawford, Hurlock, & Rogo, 1977), and civilian pilots have been taught to fly holding patterns (Feurzeig & Lukas, 1971; Trollip, 1977) through the use of CBS. Other studies include preliminary skills training for "A" school students in the operation of the oscilloscope (Stern, 1975), and titration experiments for college students (Hollan, Bunderson & Dunham, 1971). These efforts represent only a sample of the work that has been done in the area.

CBS materials are often programmed within the context of learning strategies or content sequencing algorithms. For example, Lahey and Coady (1978) have just completed another of several studies investigating the effectiveness of a learner controlled lesson that gives basic electronics school students practice with a simulated multimeter. The resulting data thus added to the knowledge bases of both learner strategies and CBS.

Other interesting uses of CBS, which are unrelated to training performance-oriented skills, have emerged in the literature. Rigney and Lutz (1976), for example, were interested in the effects of imagery on learning and used graphic simulations of a battery and processes such as ionization and reduction to teach abstract electrochemical concepts.

In summary, the research described above has generally suggested the following training advantages for CBS: Increased trainee proficiency, time savings, cost effectiveness, and high student acceptability. It appears that CBS has the potential to be a widely applicable training methodology; however, the manner in which student and task characteristics interact with fidelity variables remains to be determined. For example, one study, which used simulation that was low in appearance fidelity and relatively high in functional fidelity, resulted in lower student acceptability of CBS training materials than a previous one, that had utilized the same system and similar materials (Crawford, et al., 1977). It was not clear whether the lower acceptability in the latter study was the result of using students with more previous real-world practice, attempting to train more complex skills, or both. In other words, it was impossible to seperate out unique effects of fidelity and student characteristics.

Another fidelity question of interest pertains to the interactive nature of graphic simulation. That is, how interactive or functionally similar to the real-world must a graphic simulation be in order to produce the desired training results? This certainly has implications for determining whether successful training achieved by CBS is due to the unique capabilities of an interactive CBS system or could be achieved by some less expensive medium such as slide projections. There is a study in progress at the Navy Personnel Research and Development Center (NAVPERSRANDCEN) that is attempting to control the interactive factor; these data should help to classify some of the issues raised above (Hurlock, Note 1).

Questions regarding the effects of appearance and functional fidelity must be answered in order to predict the transfer effects of CBS or any other variety of simulation. The transfer issue has been in the literature for years and has yet to be resolved. However, while the amount of fidelity required to achieve positive transfer of training is still of central interest, there is a new slant to the question. Recently, more emphasis has been placed on the manner in which a simulation is used, i.e., its instructional context, than its similarity to its real-world counterpart. (For a more detailed discussion of the problem, see Crawford and Crawford, 1978).

Periodically, attempts have been made to establish predictions of transfer of performance skills as a function of fidelity (e.g., Miller, 1953a), but these predictions have not been based on data collected systematically, and, in some cases, have not been data-based at all. Thus, if researchers and decision makers are to take maximum advantage of CBS as a training methodology, it will be necessary to take a systematic approach to empirically determining how all of the pertinent variables act and interact with each other.

CBS SYSTEM FEATURES

Knowledge regarding the relevance of system features to effective and efficient training is also an area of newly emerging interest. However, some trends are beginning to appear as a result of research experience with various systems, and these will be described here.

CBS in clearly different from standard CAI in that graphics are used extensively in place of text. This places an entirely unique set of requirements on software development, which can be facilitated or hindered by the system hardware.

A good example illustrating some of the differences can be found in the report of a project designed at NAVPERSRANDCEN to evaluate the PLATO IV computer-based instructional system (Hurlock & Slough, 1976). The authors provided detailed reviews of eight experimental CAI lessons that were developed and used for the project; four used simulation and four did not. The simulation studies used a combination of computer graphics and microfiche for 80 percent of lesson materials with only 20 percent text. The non-simulation lessons utilized graphics for 33 percent of the materials and 67 percent text. The figures for the simulation lessons reflect the fact that graphics were used as a response mode 50 percent of the time. That is, half of the time, student performance was judged on manipulations of the graphic simulations instead of on multiple choice or constructed responses.

Thus the NAVPERSRANDCEN research shows the extensive role of graphics in CBS. Some of the specific system capabilities need to support this kind of development are discussed below. Consideration will be given to storage capabilities, display technology and input devices, presentation capabilities, and data collection.

Storage Capabilities

Hurlock and Slough (1976) reported that simulation lessons used to evaluate PLATO IV required an average of 50 percent more space for storage of material for each on-line hour than did the lessons that did not use computer graphics extensively. While the PLATO IV system is capable of providing this kind of storage (as would be the case with any large network system), it is dedicated, in philosophy, to the support of many lessons requiring small amounts of extended course storage (ECS) rather than a few lessons with high amounts. As a result, the NAVPERSRANDCEN lessons could only be run when user load was low, or researchers had to accept decreased terminal utilization as a result of increased ECS demands/lesson complexity. Therefore, one of the primary requirements of a system that is going to be used for simulation is not only sufficient storage but also a determination of the additional requirements that will be placed on the system. If network systems are to be used, managers will have to make the appropriate provisions; otherwise, stand-alone systems should be used.

These comments are based on requirements of computer graphics and do not adequately reflect features of alternative simulation displays such as random access slides. This medium is limited to a set number of slides that can be accessed at any given time (usually 80), and response time is quite slow so that it is inappropriate for complex, interactive simulation. The best use of slides may be as a supplement to interactive graphics. The General Electric Training System (GETS) is one stand-alone system that has incorporated the capabilities for this combination.

Microfiche displays are another alternative for two-dimensional simulation: Researchers in the NAVPERSRANDCEN PLATO IV project found that microfiche production phases were too involved and resolution of the displays too poor to be acceptable. This was four years ago, however, and the sophistication of the medium has increased considerably. Joseph Rigney of the Behavioral Laboratories at the University of Southern California has just completed a study using microfiche for teaching simulated troubleshooting. Rigney feels that the microfiche approach compares very favorably to the use of computer graphics (Rigney, Note 2).

Other alternatives may be provided by several possible configurations of videodisc and microtechnology. Videodisc is an inexpensive, high density storage medium, which, in combination with sufficient computer support, could be used for two-dimensional simulation. At this point in time, statements about potential applications of videodisc are pure speculation so it will be intersting to see what the research will show in the way of cost and instructional benefits tradeoffs.

CBS has been implemented on systems with both CRT and plasma panel display screens. The plasma panel, as used in the PLATO IV and GETS systems, was judged very favorably by the authors and students who participated in the NAVPERSRANDCEN PLATO IV evaluation project. These persons felt that displays were highly readable and did not cause fatigue or eye strain, and the authors commented on the ease with which displays could be coordinated with touch panel input. They felt that the panel was very useful for simulation and other interactive tasks (Hurlock & Slough, 1976).

While the plasma panel is limited to the colors of black and amber, this may not be too much of a limitation in that the effects of color on instructional effectiveness are not clear. Kanner (1968) found that the minimal use of color seemed to help students to identify important information. The majority of the research in the area, however, reports no differences between color and black and white presentations on learning (Gulliford, 1973).

The CRT screen, such as that used in the TICCIT system, is capable of color displays and has at least two advantages over the plasma panel. One is that the hardware is compatible with the videodisc and if the expected benfits of that medium are realized, systems with CRTs is that recent developments, such as raster scan technology, promise increased memory with simplified circuitry and lower costs; such features would be clearly beneficial for two-dimensional simulation.

Input devices typically used for CBS include a standard keyboard (e.g., Lahey, Crawford, & Hurlock, 1975), the touch panel (e.g., Crawford, et al., 1976), and the lightpen used with GETS (Radsken & Grosson, 1975) and planned for use with simulation on the TICCIT system. In rather unique applications, Feurzeig and Lukas (1971) and Trollip (1977) utilized a joystick interfaced with a computer-based instructional system for recording student input on "flying" holding patterns.

While it would seem that the use of the touch panel or joystick would be preferred to the lower fidelity input devices, effective training was demonstrated in all four applications. Additionally it should be kept in mind that for some portion of any training situation, the keyboard will provide an inexpensive and perfectly adequate means for evaluating student progress. Input device features and how they relate to training effectiveness need to be determined as part of the fidelity research mentioned earlier.

Presentation Capabilities

One obvious problem that emerged from the findings of the NAVPERSRANDCEN studies (Hurlock & Slough, 1976) was that network systems such as PLATO IV, which connect the computer to the terminal by telephone lines, are not the best systems for presentation of simulation materials. Transmission errors between the computer and the terminal, which do not seriously disrupt a standard CAI lesson, do distort the simulation display. This often causes students to have to start over on complex behavioral sequences and results in considerable frustration. Systems such as TICCIT or stand-alones are not subject to these problems.

System response time is also an important factor to be considered. Observation suggests that slow system response time, as caused by hardware limitations of heavy user loads, lowers acceptability (and presumably pedagogical effectiveness) in students who have had previous experience with the real-world counterpart of the simulation (Crawford, et al., 1977). As mentioned earlier, the results are confounded, but it is clearly an area needing research. Once again, stand-alone systems may be the best solution. GETS, for example, has been designed specifically to support interactive graphic displays. This system is described as a state transition device based on string-oriented, as opposed to number-oriented, processing (Rupp, 1976). One result of this design is faster system response time. GETS, for example, is approximately five times faster than PLATO IV. It is expected, though not substantiated, that the architecture of a system like GETS is conducive to ease and speed of courseware development. For example, graphics developed in the GETS system are origin-oriented at any given time. The result is that they can be moved around the screen to create new displays with very little reprogramming. A research effort that is much needed would compare requirements of identical sets of materials on different types of systems in terms of programming time, required skill levels of programmers, and overall costs.

Data Collection

Given that the primary evaluation issue in CBS is transfer of training, data comparing CBS performance to real-world performance is a top priority for future research. However, some of the benefits of data collection within the process of CBS should not be overlooked. For example, Lahey and Coady (1978) hard copied outputs of the "trail" (each response made during the lesson) of each student and were thus able to assess preferred learning strategies in a learner controlled lesson.

The collection of student latency data, which is possible in most CAI systems, can also be useful. Williams (Note 3) has proposed a theoretical model of student processing capacity suggesting that latency information can be used to evaluate levels of student knowledge. There are also implications here for the use of this type of data for validation efforts. Thus, capabilities for flexible and assessable data collection should always be considered in the design of future systems.

SUMMARY AND RECOMMENDATIONS

The research efforts reviewed here demonstrate the potential effectiveness and efficiency of CBS for training certain performance-oriented skills, to certain students, under certain circumstances. Assumming that these positive findings will be more generally applicable, it is now necessary to collect data and develop a contingency algorithm from which predictive statements can be made about specifically when, how, and for whom the methodology can be used most appropriately. Recommendations will be made here that parallel the two major portions of the body of the paper: Training considerations and CBS system features.

To begin with, it is necessary to determine the combination of student and task types that will optimally benefit from training by CBS. It will then be necessary to specify how these factors interact with varying levels of appearance and functional fidelity with respect to transfer of training. Researchers have suggested that a worthwhile approach to this matter might be found in emphasizing functional fidelity as it relates to instructional design. Variables of interest, within this context, are student-curriculum interaction (the amount necessary), input device technology (comparisons of light pen to touch panel interaction), cues present in the simulation materials (regarding the degree to which they must be similar qualitatively and quantitatively to those present in the real-world), and the roles of feedback, task analysis, and learning strategies. This line of research, then, would be centered around the tradeoffs between "good" instructional design and fidelity levels.

The other area of research to be discussed here, that of system features, is one that should probably be initiated after some of the previously mentioned issues have been resolved. That is, it is difficult to optionally design system features when the basic learning parameters remain in question.

Experience indicates that, given state-of-the-art equipment, the ideal system configuration, i.e., one incorporating all features that have been found to be useful for training, could be characterized in the following way:

1. The system should be stand-alone and designed to support extensive use of interactive graphics material in terms of a flexible authoring language and presentation capabilities; these capabilities would permit fast system response and sufficient storage.

2. The system should have a touch panel or light pen and a keyboard for student input. This combination would provide a mix of high fidelity interaction and constructed responses.

3. A CRT would seem to be optional since it would provide the ideal display in that color could be used if desired. The system also would be amenable to modification to take advantage of advances in the technology such as videodisc.

4. The system should posess both a computer graphics and microfiche or slide capabilities thus permitting presentation of graphic simulations in conjunction with photographs of real-world objects.

5. The ideal system should also have capabilities for collection and hard copy of "trail" and latency data. While the feature would not affect the quality of the simulation, it would enhance the value of CBS as a research tool.

Research to-date indicates that combining these features could produce a CBS system of maximal effectiveness; the question of efficiency remains. Future research should examine these features for areas of possible reduction in that the total suggested configuration is probably unnecessary. It seems probable that the "ideal" system could be streamlined for cost-effectiveness while maintaining the same quality of instruction. For example, the use of microfiche as an alternative, rather than as a supplement, to computer grahpics may prove to be a reliable finding. Likewise, videodisc may be a low-cost solution to storage problems.

As stressed eariler one of the most important research requirements is a comparison of authoring capabilities, developmental times, and a cost analysis of programming the same training materials on a range of systems. This would provide useful information in terms of overall effeciency of the different system configurations.

While all of the factors mentioned should be taken into consideration of the design and purchase of CBS systems, rapidly increasing technological advances require that future developments be anticipated. For example, at the present time network systems are more cost effective than stand-alones when a large number of terminals is required. However, this will not be the case in a few years when microprocessors, working together, will give small systems most of the functions of large ones at a fraction of the cost. Thus, the final recommendation for research in the area of CBS is to approach CBS training with a futuristic orientation to ensure maximal utilization of newly emerging technologies.

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